High-speed rail alignment generation and optimization using GIS

Abstract:

GIS-based analysis is used to generate, evaluate and optimize alignment alternatives for high-speed rail projects across the world. With specific reference to the California High-Speed Train Project, this paper will demonstrate how quick detailed analysis can both save money and reduce environmental impacts.

The studies make extensive use of terrain and land use analysis along with complex geometric requirements to evaluate feasible routes and their relative costs and impacts. The information is also used to inform alignment decisions during the detailed engineering stages of the project.

This paper will use case studies from the California project to illustrate the use of GIS as an aid to understanding the local environment, as an analytical toolkit, and as a method of data management for rail alignment optimization.

The methodologies for using GIS to help guide and design large scale engineering projects will be discussed, and the results and benefits will be demonstrated.

Authors, Biographical Sketch:

Roland Martin was a Senior GIS Consultant for Arup located in Los Angeles but recently relocated to the Singapore office. He has over seven years’ experience in a wide range of areas of GIS, with particular expertise in Acoustics, Hydrology, and High-Speed Rail. Roland was GIS lead on the Palmdale-Los Angeles section of the California High-Speed Train Project.

10 Hoe Chiang Road, #26-01 Keppel Towers
Singapore 089315
t +65 6411 2500  d +65 6411 2344
www.arup.com

Cary Greenwood has provided integrated GIS support and analysis for a phase 1 high-speed rail alignment. As the GIS lead on the project, Cary managed all geospatial data transactions for geospatial databases and supplied GIS/CAD data integration to translate valuable data assets. This included land use analysis and land parcel totals. Additionally, Cary is a GIS Analyst leading support to the California High-Speed Rail design process.

12777 West Jefferson Boulevard Suite 100
Los Angeles CA 90066 USA
t +1 310 578 4400  d +1 310 578 4553
www.arup.com
Introduction

High-speed rail (HSR) is increasingly relied upon across the world, with systems already in operation across Europe and Asia, and under development in numerous countries. At its most effective, HSR functions as a component within a wider transportation network, offering passengers a means to travel between cities more quickly, efficiently, and sustainably than by other means.

However, HSR has very specific engineering requirements, such as the need for straighter routes and wider tunnels to avoid passenger discomfort without losing speed. Recent HSR projects such as the UK’s High Speed 1 have enabled a deep understanding of such constraints, where they are considered at every stage of the design process.

A Geographical Information System (GIS)\(^1\) is a set of tools and techniques for collecting, managing, analyzing, and displaying geographical data. A GIS acts as a central data repository for incoming information throughout a project’s lifespan, while allowing users to view, query, and analyze data to reveal relationships, patterns, and trends. GIS is particularly effective over broad geographical areas, and so has proven tangible benefits for large infrastructure projects, such as rail and highways.

Suitability analysis

Optimal route distances for HSR depend on local conditions, but it typically competes best against air travel when train journey times are between around two and four hours. Within such journey times, connections with other local services often allow HSR systems to offer travelers a quicker door-to-door journey than flying.

Initial suitability analysis for HSR should therefore focus on the population centers within the study area – their relative sizes and densities, and the distances and connectivity between them. Evaluating existing population and growth rates of potential destination cities are critical steps for establishing preliminary destinations. The vast majority of California’s population centers exceeding...
140 000, for example, will be directly or indirectly served by the state’s proposed HSR network (Fig 1).

Much of the information required for this initial analysis is available within existing GIS datasets, typically through aggregated census data or more detailed household surveys, and additional information such as population growth rates can easily be imported from other sources if available.

Developing a comprehensive GIS database at a very early stage in a project enables subsequent stages to build on this existing information rather than needing to recreate it, and this is as true in HSR as any other type of infrastructure project.

Having identified the target destinations for the HSR network, the study then begins to focus on potential route corridors between each city pair. Typically, a good starting point is to assess existing transport links for suitability – if a new route can run alongside an existing highway or rail link, the environmental impacts will be lessened.

![Figure 2 - Candidate HSR corridors with south-east Australian terrain features.](image)

The potential for connectivity between locations may, however, be severely limited by regional conditions such as topography. Existing freight and passenger rail routes may be able to cope with this using sharp turns and switchbacks, but due to HSR’s requirements for flat curve radii and relatively shallow gradients, mountainous areas can quickly increase the cost of a planned alignment. As a result, complex terrain should be bypassed wherever possible, even though this may result in longer routes. Similarly, protected areas, rivers, and water bodies should generally be avoided.
Arup has conducted feasibility studies for rail corridors in various locations around the world, including HSR projects in North America, Africa, and Australasia. In the latter, the firm undertook a feasibility study for an HSR corridor in south-eastern Australia between Melbourne, Sydney and Brisbane (Fig 2), which was presented to the Department of Transport and Regional Services. The team used the program ArcGIS(2) to analyze population centers, soil types, terrain and environmental impacts. The initial corridor options were mapped onto this analysis, enabling consideration of the relative impacts and advantages of the different primary route corridor alternatives. The study gave a recommendation for a preferred alignment and an assessment of the commercial and financial viability of such a project.

Such options offer good starting points to be examined in more detail as the project progresses. Once the broad corridors have been identified for a proposed HSR network, they need to be narrowed into specific routes. Certain corridors may prove impossible due to the sheer volume of constraints, while others previously thought not viable may in fact be worth considering.

![Figure 3 - Route alignments generated in Quantm: anticipated costs range through a spectrum from dark blue (least), via light blue, green and orange, to red (most).](image)

In geographically complex areas, the only realistic means of assessing the possibilities of different route corridors is to examine actual alignments. This process of detailed route assessment allows engineering teams to quickly generate and assess large numbers of different alignment options, which can be easily developed into complex optimized routes. The analysis can be carried out manually using GIS software, or using specialized alignment assessment packages.
This process requires knowledge of the specific engineering requirements of HSR and an understanding of the local geographical environment from the GIS database. Following the input of contextual information and constraints, various types of alignment software can allow for a detailed cross-examination of the local terrain, ownership or infrastructure constraints giving a more informed localized interpretation of the alignment options.

While it can only be used to guide decisions, this process is extremely useful for the route assessment stage, finding alternatives that otherwise might never have been considered or may have been unfairly discounted, and enables design teams to compare and optimize solutions that may not have otherwise seemed viable. Compared to traditional alignment engineering techniques, investigating potential route alternatives becomes a much faster and more straightforward process, particularly through constrained or topographically complex areas.

**Localized studies**

Having identified the initial route corridors, and with some understanding of the route options within them, the next stage is to start a detailed examination of the localized constraints. The focus of the project becomes less a high-level GIS study and more a detailed engineering solution, but the background information gathered for the early stages of the project still plays a fundamental role in the later stages.
As already noted, HSR has a very particular set of engineering requirements. For instance, to achieve speeds above 200mph, alignments need long sweeping curves. Fig 4 shows an operational HSR junction in France, where the alignments are noticeably straighter than roads and other rail in the area. The requirement for straightness must, however, be balanced against the need to minimize impacts to protected areas, private properties, and agricultural land, while also keeping costs as low as possible. In fact, the range of limitations is often so complex that it may be impossible to meet all of them.

In mountainous areas, the primary limitation is cost. Lengthy tunnels and high viaducts quickly make alignments extremely expensive, so a careful balance between too many of either has to be found. Conversely, unless requirements call for stations in particular locations, heavily developed areas should be avoided due to impacts on residential, commercial or industrial properties, while at the same time avoiding flood zones.

Seismically active areas add another dimension. Some faults are better understood than others, and so to err on the side of caution, fault zones may be established and cover huge tracts of land which would potentially require widespread redesign of rail infrastructure in the event of seismic activity. Even outside the fault zone itself, adjacent areas can be

Figure 4 - HSR alignments crossing the Rhône near Avignon, France.
extremely susceptible to landslides, soft soils, or liquefaction. Tunneling through gas pockets or historic oil wells should also be avoided wherever possible.

**Figure 5 - HSR alignments under consideration and related constraints in the San Gabriel Mountains, southern California.**

Fig 5 shows one of the mountainous sections of California’s HSR system, just north of Los Angeles, but here the complexity of the terrain is only one of the variables to be considered. There are also developed areas close to the mountains, several major faults cross the region, and valley areas are susceptible to flooding. GIS was used to visualize and analyze the constraints side-by-side, enabling a better understanding of the complex relationships between them.

Flood plains and waterways often necessitate raising the alignment and adding elevated crossings, and more geographically extensive factors such as national parks, endangered animal habitats, existing infrastructure, graveyards, and archaeological sites can further constrain the design process.

In rural areas, the primary concern should be to keep close to existing rail, road, or utility corridors, but even when HSR alignments use existing transportation corridors it is often difficult to avoid deviating for some portion of the proposed alignment, so here property impacts need to be kept to an absolute minimum. This often requires local knowledge. For instance, in much of North America properties are subdivided in north-south and east-west lines, and so impacts can be minimized most effectively by planning new infrastructure to follow these lines wherever possible.
In urban environments, the constraints can be entirely different (Fig 6). The primary cost for an alignment through a city is typically for right-of-way acquisition, but cost is not the whole problem. Commercial and industrial properties may have considerable financial implications, but taking residential properties and public amenities are likely to have much greater impacts on the community. Choosing the appropriate corridor depends, however, on the availability of good quality digital land use data.
Within the United States, land parcel datasets are often tracked and catalogued by individual counties within a state, some of which are further behind in digitizing land parcel records than others. On one HSR assessment carried out by Arup parcel data was acquired in three different formats depending on the county: scanned documents in PDF format, CAD drawings (Fig 7), and full GIS datasets.

The scanned documents needed to be accurately georeferenced by converting them to image files, recropping them to the correct extent, and then geolocating them in GIS using other base datasets such as the county boundary to help identify the correct location for the image.

Assessor datasets can require complex processing in order to acquire valuable land ownership information before they can be used for digital analysis. Even with this processing, the original source data may still contain additional details, so they are preserved for use throughout future stages of the project.

Once all land parcels have been collected into a geolocated dataset, the information can be used to inform the engineering. Any locations where the alignment under consideration deviates from existing transportation corridors can be quickly identified and the information used to understand or minimize the impacts.

Only through the use of GIS is it possible to visualize all of this information simultaneously and quickly, and thus easily understand all the relative impacts that can result from the route under development.

**Next steps**

Informed by the preliminary alignments and the background GIS datasets gathered throughout the project, design teams can make more appropriate engineering decisions more efficiently. The rail alignment can be better designed around the local conditions. Improvements to such local conditions could be seen in grade separations and utility diversions can be optimally located to minimize disruption as well as rail structures and trenches more cost-effectively designed.

But this is far from the end of the story. The geographic information gathered from inception and during design is used throughout the project phases until completion. A right-of-way assessment, for example, uses parcel data from GIS as its basis to gather cost information for each alignment alternative.

Large engineering projects have complex environmental requirements, and visual impact assessments and ecological studies continue to generate further GIS data, which build on the information from earlier project stages. Environmental modeling information is also gathered and processed using GIS and loaded into acoustic and air quality modeling software, such as *SoundPlan*(5) and *NoiseMap*(6). Using Arup’s prior expertise with the packages and the experience gathered on earlier stages of the project, it is possible to convert the background and engineering data into the exact form required for the
specialist modeling. The output information is then loaded back into a GIS database (Fig 8) and used to generate property counts and demographic impacts so as to quantify the relative environmental impacts of each alternative.

Figure 8 - Completed noise map showing proposed alignment, buildings, and contours

GIS can also be used to help stakeholders and the community better understand public projects and for GIS professionals to spatially analyze information gathered through public input. Web-based GIS functionality can be used to give the community information in an easy-to-access, nontechnical format, and allows engineers and project managers to bring community comments into a spatial format that can be viewed and analyzed against other technical data.

Conclusion

At Arup, GIS is now fundamental to developing a large infrastructure scheme. From initial conception through to detailed design, construction and project handover, environmental modeling, and public participation, immense volumes of geographic data are gathered. On a HSR alignment, wherever it may be, GIS can help clients and project teams to understand the interdependency of the constraints, thereby delivering the best engineering solutions more quickly and easily.
References

(1) http://arup.com/Home/Services/Geographic_Information_Systems.aspx
(2) www.esri.com/software/arcgis
(3) www.trimble.com/alignment
(4) www.esri.com/software/arcgis/extensions/3danalyst
(5) www.soundplan.eu
(6) www.noisemap.ltd.uk
(7) www.collaborativemap.org

Image credits

1 Arup/Nigel Whale; 2 Arup/ArcGIS; 3 ©Adrien Patane, Trimble; 4 Arup (including Microsoft product screen shots reprinted with permission from Microsoft Corporation); 5 California High Speed Rail Authority Maps Palmdale to LA http://www.hsr.ca.gov/docs/newsroom/maps/Palmdale_to_LA.pdf; 6 - 7 Arup (including Microsoft product screen shots reprinted with permission from Microsoft Corporation); 8 Arup/NoiseMap (including Ordnance Survey data ©Crown copyright, all rights reserved)
High Speed Rail Alignment Generation and Optimization using GIS

ARUP

Cary Greenwood, Arup Los Angeles
Roland Martin, Arup Singapore
Introduction

• Why HSR?
• Optimization Considerations
  - Route corridors
  - Constraints
  - Use of Quantum
• Localized studies
  - Mountainous areas
  - Dense / Urban areas
  - Parcel ownership
  - Generating an engineered alignment
• Conclusions

Why HSR?

High Speed Rail vs. Other Modes of Transportation

Optimization Considerations
What is High Speed Rail?

- US Standards are greater than 110mph
- Global standard considered greater than 186mph
- Maximum recorded speed is 357.2mph

California - major population centers

California High Speed Rail is expecting to carry up to 39,000 people per hour, the same as a 10-lane freeway, with a fraction of the property take.

Existing Corridor Analysis

Environmental Constraints - Biological

Physical Constraints
Environmental Constraints - Residential

Constraints - Utility Corridors

Constraints - Flood Zones

Constraints - Cultural Resources

Constraints - Overall

Weighted Options - Quantm
- County-based Data Acquisition
- Multiple Formats
  - SHP
  - DGN
  - PDF
- Georeferencing of PDFs within ArcMap
- County Data Summary
  - Number of parcels intersected
  - Market value totals
Land Parcel Registry

SHP

September 29 – October 2, 2013
Indianapolis, IN

Georeferencing Benefits
- Original labeling is sustained
- Feature symbology is left intact
- This original notation makes for better decision-making
- Strong benefits for preliminary assessments

Georeferencing Drawbacks
- Contextual shapefiles are necessary for contextual georeferencing
- Time required for referencing
- Struggle for accuracy

Land Parcel Registry

Automation Model

Iteration through all potential alignments

Parcels

Clipping Area Clipped

Percentage Impacted

Add alignment names based on filename

Generating an engineered alignment

Environmental impacts
- Noise and Vibration
- Biological Resources
- Agriculture Resources
- Cultural Resources
- Geology / Soils
- Archaeology
- Land Use / Planning
- Aesthetics
- Air Quality
... and more…
Conclusions

Thank you!

Cary Greenwood
cary.greenwood@arup.com

ARUP